DOCUMENT RESUME

ED 246 866 IR 011 198

AUTHOR	Finegold, Lawrence S.; And Others
TITLE	Simulated Three-Dimensional Computer Graphics Training Display for Air Weapons Controllers. Final Report.
INSTITUTION	Air Force Human Resources Lab., Wright-Patterson AFB, Ohio.
SPONS AGENCY	Air Force Human Resources Lab., Brooks AFB, Texas.
REPORT NO	AFHRL-TP-83-62(I)
PUB DATE	Apr 84
NOTE	54p.
PUB TYPE	Reports - Research/Technical (143)
EDRS PRICE	MF01/PC03 Plus Postage.
DESCRIPTORS	*Animation; *Computer Software; Display Systems; Instructional Materials; Microcomputers; *Military Training; *Simulation; *Three Dimensional Aids; Training Methods
IDENTIFIERS	*Computer Simulation

ABSTRACT

The research and development project demonstrated the viability of a simulated training system to address training issues related to three-dimensional air intercept tactics and geometry, and resulted in the production of two videotapes for use in the United States Air Force Interceptor Weapons School. An introduction discusses the overall development of the system, which provided the capacity to display and control up to three aircraft in a defined airspace. Additional supplemental graphics to address specific training uses were also developed using full-color, raster-scan, animated microcomputer display technology. Project background, objective, approach used, and results are discussed, including a summary of the major technological difficulties encountered. An overview then describes the system and provides details on hardware and firmware, applications software, the visual scene, two versions of the aircraft display and control software, special graphics relating to training issues, and system use. A final discussion includes a summary, an outline of technical issues, and conclusions. Sixteen references and a 28-item bibliography are included. (LMM)

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AFHRL-TP-83-62(I)

AIR FORCE HUMAN RESOURCES LABORATORY

ED246866

SIMULATED THREE-DIMENSIONAL COMPUTER GRAPHICS TRAINING DISPLAY FOR AIR WEAPONS CONTROLLERS

By

Lawrence S. Finegold

LOGISTICS AND HUMAN FACTORS DIVISION
Wright-Patterson Air Force Base, Ohio 45433

Anthony J. Asch

Anthony J. Asch, Inc.
28 Coleman Plaza West, Suite 7E
Brooklyn, New York 11201

James C. Flaugher

Universal Energy Systems, Inc.
4401 Dayton-Xenia Road
Dayton, Ohio 45432

April 1984
Final Technical Paper

Approved for public release; distribution unlimited.

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235

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This paper has been reviewed and is approved for publication.

JOSEPH A. BIRT, Lt Col, USAF
Technical Advisor
Logistics and Human Factors Division

DONALD C. TETMEYER, Colonel, USAF
Chief, Logistics and Human Factors Division

AFHRL Technical Paper 83-62(I) April 1984

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Anthony J. Asch

Anthony J. Asch, Inc.
28 Cadman Plaza West, Suite 7E
Brooklyn, New York 11201

James G. Flaugher

Universal Energy Systems, Inc.
4401 Dayton-Xenia Road
Dayton, Ohio 45432

Reviewed and submitted for publication by

Bertram W. Cream
Chief, Ground Operations Branch
Logistics and Human Factors Division
Air Force Human Resources Laboratory
Wright-Patterson Air Force Base, Ohio 45433

AD-A144 193

SUMMARY

This work was requested by the Headquarters Tactical Air Command through a Request for Personnel Research (RPR 79-08). The objective of the RPR was to improve the training of Air Force air weapons controllers by development and application of advanced training technology. The technology to be developed was a computer graphics simulation of three-dimensional airspace intercept tactics and geometry. Successfully performing the jot of an air weapons controller requires a thorough understanding of these issues.

Since current training devices and operational equipment provide only a two-dimensional display, the complexity of intercept geometry has been difficult to display and teach. Specifically, the desired capability included simulation of heading crossing angles, intercept vectors, turn points for intercepts, and bearing and range to target. A simulated three-dimensional computer graphics display system was developed to address these issues. Videotapes of complete aircraft intercept mission scenarios were made for use by students at the USAF Interceptor Weapons School (IWS), Tyndall AFB FL. These tapes have been incorporated into the IWS training program. In addition to reporting the work accomplished, Volume I of this paper discusses technical issues identified during this effort. Volume II provides a users guide to the computer system and explains in detail how the system is operated, both for interactive (live-flying) control of the aircraft and for developing scripted mission scenarios for producing videotapes.

PREFACE

An exploratory research and development project was conducted to examine the feasibility of developing a simulated three-dimensional computer graphics training system for Air Force air weapons controllers. This work was performed as part of the research and development support being provided to the tactical command and control community by the Ground Operations Branch, Logistics and Human Factors Division of the Air Force Human Resources Laboratory. This effort supports Project 3017 - Technical/Team Performance and Training, Mr. Bertram Cream, Project Scientist; Task 3017-08, Crew Group Team and Unit Performance and Training, Mr. Bertram Cream, Project Scientist; Work Unit 3017-08-02, Training for Air Weapons Controllers Using Advanced Computer Graphics Technology, Mr. Lawrence Finegold, Project Scientist.

ACKNOWLEDGEMENTS

Acknowledgements and grateful appreciation are extended to the following individuals:

Mr. Bertram Cream for initiating and providing continual managerial support to this effort.

Dr. Lawrence E. Reed and Dr. George A. Frekany for their knowledgeable human factors input during the course of the effort.

MSgt Al Cox and TSgt Larry Cook for their invaluable assistance in developing the software for the mission scenarios, much of which was done at night and on weekends.

To Mrs. Martha Balzer and Mrs. Katherine Paris, without whose outstanding efforts this paper could not have been written.

To the air weapons controller community, including the staff at HQ TAC/DOYT, Langley AFB VA; 502 AWACW, Tinker AFB OK; 3625 TTS, Tyndall AFB FL; and especially Col Foxwell, Capt Gene Glover, Capt Chris Lauritzen, and the instructor staff of the USAF Interceptor Weapons School, Tyndall AFB FL, in support of whom this effort was conducted and whose job it might make a little easier.

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SECTION 1 - INTRODUCTION

BACKGROUND

The primary function of Air Force air weapons controllers is to direct the flight of friendly aircraft as they intercept unknown or hostile target aircraft. This is accomplished through the use of two-dimensional graphics radar displays and voice communications with the aircraft pilots. (Although an increasing number of air weapons controllers are involved in guiding aircraft to ground targets, this project addressed issues primarily relevant to training for air-to-air intercepts.) Training for this demanding occupation is accomplished at several Air Force training organizations and at operational units. At the technical training schools, high fidelity training systems, which emulate the operational systems, provide the primary source of simulation for intercept training, as well as providing radar input for "live flying" training sorties. This equipment, while quite useful for familiarizing students with the equipment they will use at their operational units, lacks certain graphics simulation capabilities that could significantly improve the quality of intercept training.

A series of discussions with instructors from various air weapons controller training organizations identified a set of critical training issues which have been particularly difficult to teach because they were difficult to display visually to students. Most of these issues involved the concepts of intercept geometry and tactics, airspace situational awareness and flight safety. The capability to demonstrate these concepts visually in a dynamic simulated three-dimensional airspace was expected to have the most significant impact on training.

A Request for Personnel Research (RPR 79-08) from Headquarters, Tactical Air Command to the Air Force Human Resources Laboratory

identified the need for a graphics simulation capability and tasked this Laboratory to develop "special purpose 3-D [three-dimensional] displays that can provide perspective information and visually present complex aircraft geometry and airspace relationships" for air weapons controller training.

In support of this objective, the effort described in this paper was implemented specifically to support the training provided by the USAF Interceptor Weapons School (IWS) at Tyndall AFB FL. Students in the IWS training program have already completed basic air weapons controller training and are being introduced to the Semi-Automated Ground Environment (SAGE) -- Back-Up Intercept Control (BUIC) automated radar equipment. They also receive considerable additional training at IWS to improve their skills in performing intercepts using various air-battle tactics.

The IWS instruction relating to fighter guidance for intercepts consumes the largest amount of time for student training and requires that students be knowledgeable about intercept tactics and procedures, including intercept geometry, airspace utilization, and flight safety. Training is accomplished through a series of classroom lectures, combined with intercept practice using both the BUIC simulator and live sorties. However, the simulated BUIC radar system, verbal lectures, and static displays such as vugraphs or chalkboard drawings cannot show the dynamic nature of the geometry involved in performing aircraft intercepts, especially the relevant three-dimensional aspects.

The primary training problem, then, is the difficulty of effectively presenting the dynamic geometry involved in performing intercepts. For example, instructors cannot easily show students the effects of the timing of a turn on the geometry of the intercept, nor can they easily demonstrate how a heading correction given at a particular time will affect the intercept 2 or 3 minutes later. Most importantly, students cannot be shown the relationship between two-dimensional intercept geometry and the fact that aircraft are actually flying in a

three-dimensional real world. The two-dimensional radar display does not graphically show the effect of altitude separation on either intercept geometry or flight safety. Anecdotal comments from instructors indicated that the more proficient air weapons controllers have developed an ability to visualize what is occurring in the third dimension (height). Presenting this three-dimensional information to students is difficult because the training equipment presents only a top-down, two-dimensional view of the intercept.

The only training system that provides a simulated three-dimensional, dynamic view of an aircraft intercept is the Aerial Combat Maneuvering Instrumentation (ACMI) system (Altman, 1978), which is used for pilot training. This system provides an accurate, detailed representation of the flight of interceptor and target aircraft, and thus presents an excellent simulated three-dimensional dynamic representation of aircraft maneuvers during intercepts. However, it has two drawbacks that limit its usefulness for addressing the issues critical for air weapons controllers. The first is that it cannot simulate intercepts; it can only collect and record geographic position data from live flying sorties and present these data graphically. Thus, it is impossible for an instructor to develop an exact plan for a mission to demonstrate a particular issue and have the computer simulate this specific scenario. Although it would be possible to record the positional data from live intercepts, live intercepts are very difficult to fly exactly according to a prebriefed pattern. Live missions would have errors and positional changes that would change the geometry of the intercept from that originally planned. Thus, it would be very difficult for an instructor to plan a mission scenario to demonstrate specific training issues and have the mission flown precisely as briefed to show these particular situations. One of the major advantages of a simulation system is that scenarios can be planned exactly, and the computer software will fly the mission precisely as planned.

The second major drawback is that it is currently impossible to develop and present any special graphics as overlays on top of the visual scene. This type of display is absolutely essential to demonstrate the geometry involved in the various intercept tactics. Students need to be shown both the two-dimensional and three-dimensional aspects of intercept geometry, tactics, and procedures. Concepts that need to be presented include Heading Crossing Angle, Bearing and Range-to-Target, Turn Point, Effects of Timing of Turns, Cone of Attack, Interceptor Approach and Attack Vectors, Patterns for Continuing Intercepts, Effects of Altitude Separation, Direction of Initial Turn-to-Target, Re-attack Profile, Offset and Transition Points, Maintaining Airspace Integrity, and Choosing Target Headings. These concepts are illustrated in Section II of this paper and are illustrated and discussed on the two videotapes developed during this effort.

Although all of these issues are initially addressed in the basic air weapons controller training course, the entering IWS students typically have only a rudimentary understanding of how they affect the outcome of a mission. In order to provide a review and more in-depth presentation of these concepts and techniques via videotapes, the IWS instructor staff participated in the design of the aircraft display and control capability, the special graphics needed to demonstrate the intercept geometry issues, and the mission flight scenarios the simulated aircraft would fly.

OBJECTIVE

This research and development effort was initiated to assess and demonstrate the feasibility of developing a simulation training system to address the set of training issues discussed previously. The primary purpose was to supplement the training currently being offered by the instructor staff of the IWS by providing them with an improved capability to display and demonstrate critical aircraft intercept concepts and techniques that are very difficult to address adequately using the existing training equipment.

APPROACH

In order to develop a graphics simulation training capability that would address the issues deemed critical to the IWS training program, a close working relationship was developed with the IWS management and instructor staff. Frequent discussions and meetings were held with these personnel to identify the training issues needing supplemental training and to design computer graphics that would demonstrate these critical concepts and techniques. Periodic reviews were held with these personnel, both in the form of face-to-face visits and by reviews of sample videotapes (of the various displays) which were sent to the IWS staff for their critique, along with a written review questionnaire. In addition, the IWS instructor and student manuals, plus other training materials, were used as illustrations for several of the required displays relating to intercept geometry.

The initial step in this effort was to develop the capability to display and control three aircraft in a defined airspace. This allowed two interceptors to be controlled against one target, which is the ability level required by graduates of the IWS training program. The hardware chosen for this effort was an Aydin Controls, Inc., Model 5216 graphics microcomputer and high resolution color monitor. This effort required color capabilities, a high resolution pixel configuration, raster scan technology, system reliability, and sufficient memory planes to allow for visual scene animation. Aydin Controls Inc. also supplied an off-the-shelf basic three-dimensional simulation software display system, encoded in Programmable Read Only Memory (PROM). The applications software was written using the FORTH programming language and was stored on a 5.0-megabyte hard disk. This configuration provided the high resolution, full-color, animated display of either two or three aircraft. All of the flight parameters of the aircraft (e.g., heading, speed, altitude) were designed to be controllable interactively via a standard Aydin Controls, Inc. microcomputer keyboard. A grid display was developed to simulate the airspace boundaries, and several other basic

display and control features, to be described later, were established. Reviews and critiques by air weapons controller instructors were quite beneficial in defining all of these features, many of which underwent major revisions, especially the airspace display, on the basis of this feedback.

Once the capability to display and control the aircraft was achieved, more detailed discussions with the IWS project officers led to a set of training issues for which special graphics were to be developed. These focused on the geometry involved in performing stern and cutoff intercept tactics. As before, frequent discussions were held with the IWS staff to insure that these graphics were accurate and addressed the issues of primary importance. Mission scenarios were then developed to illustrate the tactics and procedures involved in performing stern and cutoff intercepts.

Finally, after the graphics were deemed acceptable, one of the IWS project officers prepared scripts which addressed the training issues being displayed and recorded these instructor scripts on the videotapes for the stern and cutoff mission scenarios. This resulted in two videotapes to be incorporated into the IWS training program.

RESULTS

This effort successfully demonstrated the feasibility of addressing critical air weapons controller training issues that had previously been very difficult to teach.

Although this effort successfully accomplished its objective, many limitations were encountered while this prototype system was being developed. Although the state-of-the-art in microcomputer technology has advanced considerably since this effort was initiated, and the hardware and software described here have many excellent capabilities, several

issues need to be considered in the planning of future related research and development efforts. These capabilities and limitations are discussed in more detail in Section III, but are listed here to provide a summary of the major technological difficulties encountered during this effort.

1. The programming language used on the graphics computer in conjunction with the firmware limits the user to approximately 32 Kbytes of usable applications software, whereas the computer can be configured to store 768 Kbytes of program code. Several graphics features had to be eliminated because of the requirement to stay within the 32 Kbytes of primary memory. This limitiation cannot currently be overcome, although it is possible that systems using other languages might allow an adequate amount of primary memory for use of additional graphics and program management software.

2. Interactive control of the aircraft by an operator using the keyboard is very difficult. A different type of input system, such as voice recognition technology, should be examined if research and development continues on this type of system.

3. Although raster scan display technology is superior in many ways to other types of display techniques, ways to minimize display flicker and to increase the frame-drawing rate need to be found. At the present time, the visual scene is redrawn only approximately twice per second. The realism of the animation would be improved considerably if the scene were redrawn at a much faster rate.

4. Very little research and development has been performed on the optimal method to display this type of simulated three-dimensional animation and on how to maximize the use of the available simulated three-dimensional cues. More human factors/human performance data are needed concerning the display and perception of simulated three-dimensional scenes.

5. There were many possible training applications discussed during the course of this effort, including use of this display as a basic introduction to aircraft intercepts, as a refresher system to address intercept geometry, and as a part-task trainer for teaching advanced concepts such as aerial combat tactics (dog fights) and pop-up maneuvers. This type of display capability could be used at these various levels of difficulty and complexity, but would require that the specific training issues at each level and the required graphics capabilities be clearly identified.

Both of the videotapes developed during this project have been incorporated into the IWS training program. Specifically, they will be shown to all students during the third week of the 10-week IWS training program. At that time students will have completed their familiarization with the BUIC equipment and will be ready to begin performing simulated intercepts. Thus, these tapes will primarily serve the purpose of reviewing intercept tactics and geometry before students become intensively involved in controlling intercepts on the BUIC equipment.

Time and manpower limitations on this effort did not permit a full-scale evaluation of the training effectiveness of the videotapes, although student comments have generally been quite favorable. Although it was not included in this feasibility demonstration effort, future work in this area should include a formal evaluation of the usefulness of the simulated three-dimensional training display.

SECTION 2 - SYSTEM DESCRIPTION

OVERVIEW

In order to address the training issues discussed in the previous section, display design and operations requirements were developed, including descriptions of the special training-related graphics. The initial requirement was for an animated display with full control of three aircraft within a confined airspace. The second requirement was for a set of special graphics displays to be shown as overlays to the aircraft and airspace visual scene to address the training issues. The third requirement was for the capability to develop and record complete mission scenarios directly from the digital computer output onto a videotape. During work on each of these requirements, preliminary and final products were evaluated by air weapons controller instructors and many modifications were implemented as a result of their feedback.

The computer hardware system components included a graphics microcomputer, standard keyboard, program storage disk and a color viewing monitor. This basic system was supported by a computer signal encoder, plus a standard videotape recorder and color television monitor for making videotapes.

The basic simulated three-dimensional graphics software and the operating system reside on the microcomputer in Programmable Read Only Memory (PROM) microprocessor chips. This computer code is supplemented by an additional applications package that contains the instructions for displaying and controlling the aircraft, visual scene, and special graphics.

There are two versions of the software system. The first is for "live flying" (i.e., interactive control) of the aircraft. This version is displayed on the color viewing monitor, using a high resolution visual

display, and is used primarily for giving system demonstrations. This version will be referred to as the high resolution CRT version. The second version is for producing videotapes and is displayed on the television screen using a low resolution version of the display. This version will be referred to as the TV/videotape version. The differences between these two versions will be described in more detail later in this section.

HARDWARE AND FIRMWARE

The microcomputer used to develop this graphics training display system was a standard Aydin Controls, Inc. model 5216 display computer with nine memory planes and six other display and control microprocessor boards. This is a 16-bit computer with an Intel 8086 central microprocessor. Internal to this system are a number of hardware modules, including a hardware vector generator, which enhance the graphics and alphanumeric display capabilities.

The applications software is stored on a Perkin-Elmer VF-1221 cartridge disk drive, with controller. When the computer is initialized, the applications software is loaded from the storage disk into the computer primary memory. The operator work station for interactive flying consists of an Aydin Controls, Inc. Model 8026 high resolution color monitor and a Model 5116 keyboard with 16 user-definable function keys.

For making and viewing videotapes, the system also includes a Lenco PCE-462 Color Encoder and a Lenco CSL-710D Synchronization Generator. These two pieces of equipment convert the analog RGB (red-green-blue) output from the computer to a format suitable for direct input to a Sony videotape cassette recorder and a Sharp television, although any standard color videotape recorder and television can be used.

The Aydin 5216 is a stand-alone, raster scan, full-color microcomputer display system capable of a 1024- by 1024-pixel display, although the pixel configuration is programmable to allow a lower resolution format for signal conversion to standard television scan rates for direct videotaping. A stand-alone system was chosen because it provides an alternative to the traditionally higher-cost host-bound simulators (i.e., graphics displays generated by a large, general purpose computer).

The computer code developed for this training display capability, including the disk-based operating system, was achieved in two phases. The first was the development, by Aydin Controls, Inc., of a general purpose simulated three-dimensional graphics instruction set. This package, named "AYGRAF/3D", is now an off-the-shelf software package residing on a programmable read only memory (PROM) chip. The second phase involved the development of the applications software described in the following paragraphs.

The airspace in which the aircraft "fly" is defined as part of the three-dimensional coordinate space contained in the graphics nucleus (AYGRAF/3D). All of the graphics primitives, including surfaces, vectors, prisms, spheres, and text are described in terms of this three-dimensional coordinate space. These primitives are grouped together into display lists known as "graphics objects." Each aircraft, the ground surface, and the additional information displays are described by separate graphics objects. An image transformation is associated with each graphics object, which causes the object to rotate, translate, and scale in a simulated three-dimensional world coordinate space. Thus, it is possible to position and orient each aircraft individually without altering the graphics primitives that describe it or the image transformation, translation, and rotation factors associated with the aircraft. This technique improves the animation response time for the simulation of aircraft movement.

In addition, the graphics objects are nested in the form of a tree structure allowing the development of complex hierarchical data bases. Thus, complex and different transformations of separate graphics objects can be modeled through the use of hierarchically structured simple transformations of each graphic object in the tree.

Viewing transformations make it possible to alter the apparent position of the viewer and to control the amount of the scene that is observed. In the applications software, the location of the viewer in the simulated three-dimensional space is specified, and also the direction in which to look. If the viewer were looking through a window, the position of the window would be specified, as well as the height and width of the window and the distance from the viewer to the window. Together, all of these simulated three-dimensional viewing transformations allowed the development of the panning and visual scene zoom capabilities described later.

Finally, the basic simulated three-dimensional instruction set allowed the keyboard to be used for aircraft, scene and training-related graphics control through the use of the function keys. This allowed many often-used routines to be invoked by the use of the function keys, rather than requiring an operator to type commands on the keyboard.

APPLICATIONS SOFTWARE

The use of the AYGRAF/3D basic simulated three-dimensional instruction set required that the applications software be written in the FORTH programming language. This language uses English-type words to build a graphics dictionary through the use of a threaded, linked list. Each command, procedure, and variable must be defined at some point in the program before it is actually used, because initially, the program has very few predefined words that it recognizes. Following the principles of structured programming, FORTH allows the definition of a

hierarchy of procedures. This permits the execution of complex tasks through the chaining of simple procedures.

Under the AYGRAF/3D FORTH multitasking operating system, there are two separate major tasks. One drives the animated visual scene via the construct and display routines internal to the program. The second services keyboard commands. The first is a timer-driven task to handle the actual animation of the scene. It calculates the path and rate of change of each aircraft for each frame and creates a new frame of picture data on the screen from updated image transformations. The second handles inputs from the interactive keyboard. Inputs from the keyboard, either from the alphanumeric typing keys or from the function keys, will direct the commands to the animation task to alter the aircraft flight parameters or other components of the visual scene. This task also provides all of the user-friendly interpretation and messaging necessary for the system operator or student interface to the applications program.

In order to preserve the "realism" of the display, a major priority was to achieve smooth animation of the aircraft flight. To do this, a special technique was used in which each successive frame image is built in alternate frame buffers and displayed in turn. While a given frame is being displayed, the next frame is being built into refresh memory by the graphics routines and hardware. When the entire next frame is built, the old frame is made invisible and the new frame is made visible. This "ping-pong" effect is achieved through the use of video lookup tables. This procedure achieves a smooth transition between frames and the observer does not have to watch the separate frames being built on the viewing screen.

VISUAL SCENE

Figures 1 through 3 show the whole visual scene. As can be seen from these figures, the display can be divided into four separate areas: the

airspace display, the aircraft information display, the zoom/position indicator, and the text line.

In the center of the display is a grid, viewed from the top-down position in Figure 1, which represents the ground over which the aircraft fly. The airspace lies above this ground representation. Although the ground defines the geographic area in which the aircraft are to be flown, they can actually be flown throughout a larger airspace that includes some area outside of the displayed geographic area. This reflects the "real-world" situation in which air weapons controllers are normally assigned a particular airspace, but sometimes have the aircraft fly outside of the assigned area, either accidentally or on purpose.

The airspace directly above the grid display (ground) simulates an area roughly 70 miles on each side and 28,000 feet in altitude. The visual scene may be viewed from a number of viewer perspectives: top-down, 45°-angle, and front views, as shown in Figures 1 through 3. These different angles of view allow a better understanding of the three-dimensional aspects of the display because of the different perspectives available. The visual scene may also be shifted vertically, horizontally, or diagonally through the use of the directional panning keys located on the keyboard. This movement is usually done in order to keep the aircraft centered in the viewing screen as they move through the airspace.

Dynamic information about each aircraft is displayed in the upper right-hand corner of the display. This information is provided for each aircraft that is being flown at any given time and includes data on aircraft heading, speed, altitude, type of attack committed to, current heading crossing angle, and bearing and range to the target. This display was organized so as to be similar to that actually used on automated operational equipment. When any of these data change for any displayed aircraft, the data display is automatically updated, thus providing accurate data constantly to the student.

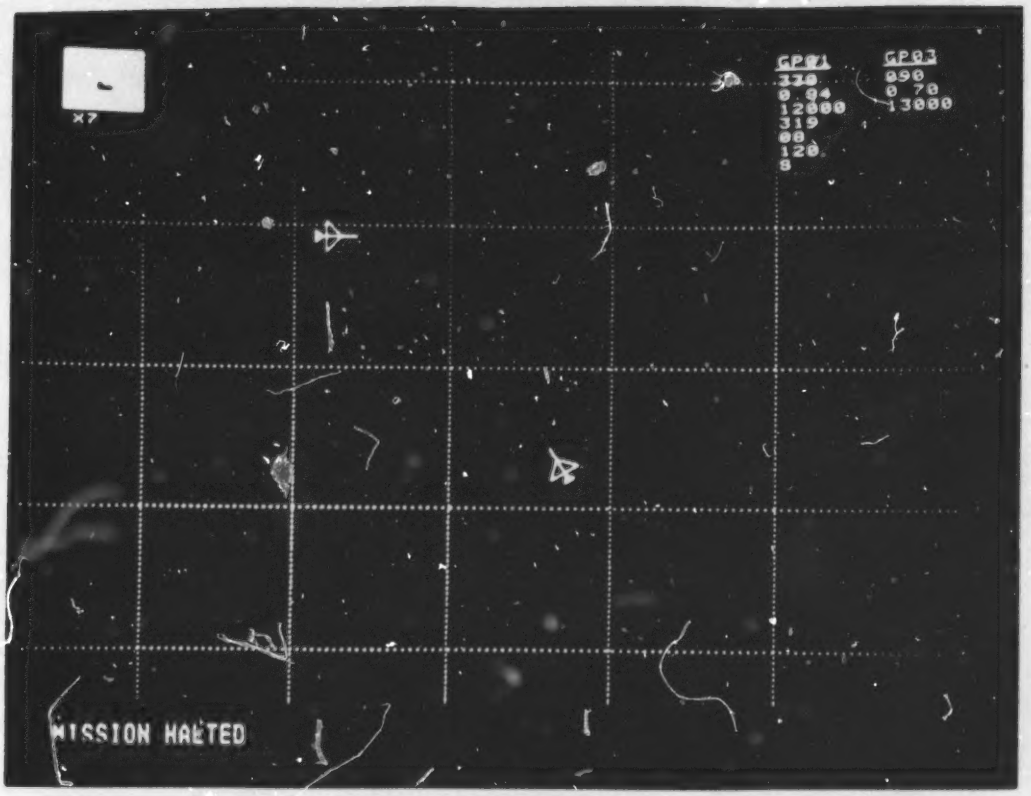

FIGURE 1. VISUAL SCENE (TOP-DOWN DISPLAY).

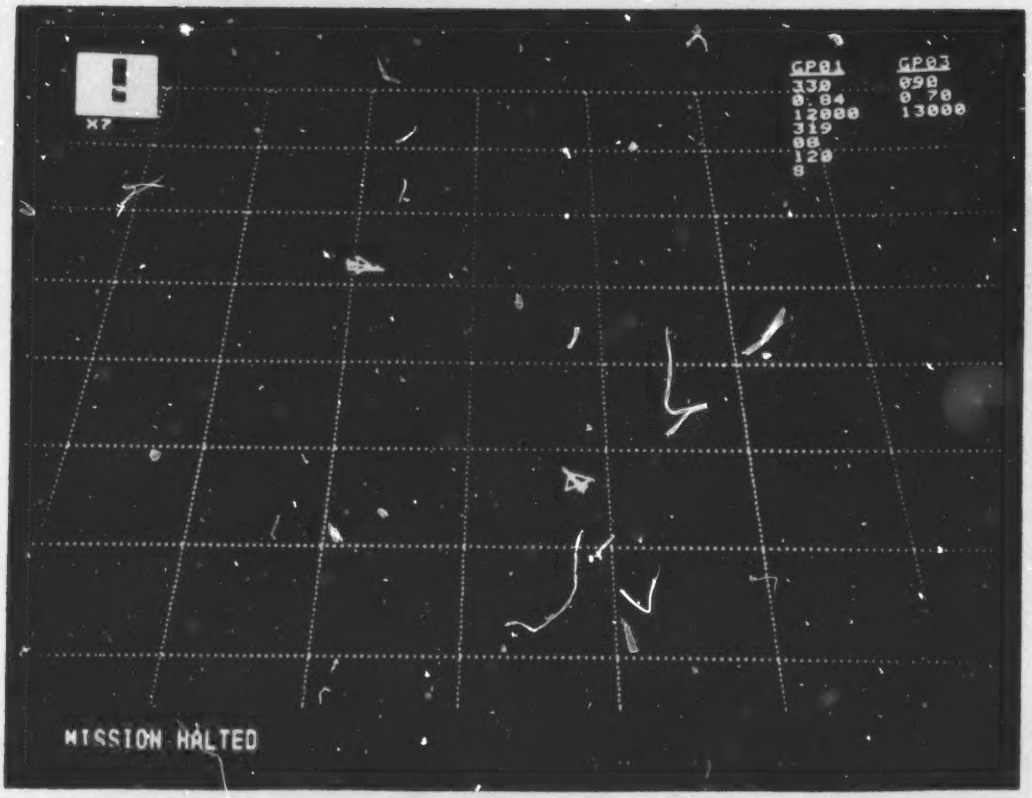

FIGURE 2. VISUAL SCENE (45°-ANGLE DISPLAY)

FIGURE 3. VISUAL SCENE (FRONT-VIEW DISPLAY).

The amount of zoom being used (i.e., the proportion of the total airspace being shown on the viewing screen) and the positions of the aircraft in the airspace are displayed in the upper left-hand corner of the viewing screen. A zoom value indicator (i.e., X1, X2, X3, etc.) is positioned at the lower left-hand corner of the zoom position indicator. There are nine zoom values available, with a zoom value of one (X1) indicating that all of the airspace is being shown and nine (X9) indicating that the smallest available segment of the airspace is being expanded to fill the viewing area. The background color of the zoom/position indicator is colored light blue to indicate the whole airspace, and the portion of the airspace actually being displayed is dark blue. Thus, it is simple to determine quickly which portion is being displayed at any given time. The positions of the aircraft within the airspace are represented on the zoom/position indicator by short, straight lines similar to the processed radar return seen on manual operational radar equipment.

Along the bottom of the viewing screen is a text line which simulates communications between the air weapons controllers and the pilots. Although the aircraft are controlled using a command language similar to that used with actual aircraft pilots, there are differences caused by the fact that the operator is actually communicating with the computer by typing. This text line also provides error messages when improper inputs are made or when aircraft are requested to perform maneuvers they are not programmed to perform.

AIRCRAFT DISPLAY AND CONTROL

As mentioned before, there are two versions of the software used for this system, a high resolution CRT version for interactive control of the aircraft, and a low resolution TV/videotape version used for producing videotapes. The differences between these two versions will be addressed in detail later in this section. However, the major difference between

these two versions is the manner by which the aircraft are controlled. In the interactive version, the interceptor aircraft are controlled via the keyboard, whereas the target aircraft may either be keyboard controlled or fly a scripted route profile (flight plan). This latter capability allows an operator to control interceptor aircraft flying against a target whose flight path is unknown to the operator. In the flight plan version, although some interactive control is available, all aircraft are primarily controlled from scripted flight plans and the keyboard is used only to modify the viewing controls (zoom, pan, etc.). Either two or three aircraft may be displayed and controlled at the same time, providing the capability to "fly" either one or two interceptors against a target aircraft. Through a series of interviews with training personnel and a review of relevant training material, a set of commands were developed that are quite similar to the language actually used to control real aircraft (e.g., GP01 TURN RIGHT 090).

SPECIAL GRAPHICS RELATING TO TRAINING ISSUES

After most of the software for visual scene and aircraft display and control was developed, discussions were conducted with IWS instructors to identify the specific training issues to be depicted through specialized graphics and mission scenarios. The intent was to use these additional graphics, when appropriate, as overlays on the visual scene and to describe them as part of the instructor voice script on the videotape.

Intercept Cone of Attack.

When an interceptor is approaching a target, it is critical that it be within the "cone of attack" that is appropriate for the intercept tactic being used. Figures 4 and 5 present the cones of attack for the stern and cutoff attacks. Although the appropriate cone of attack was developed for the pursuit attack, it was not photographed. These cones

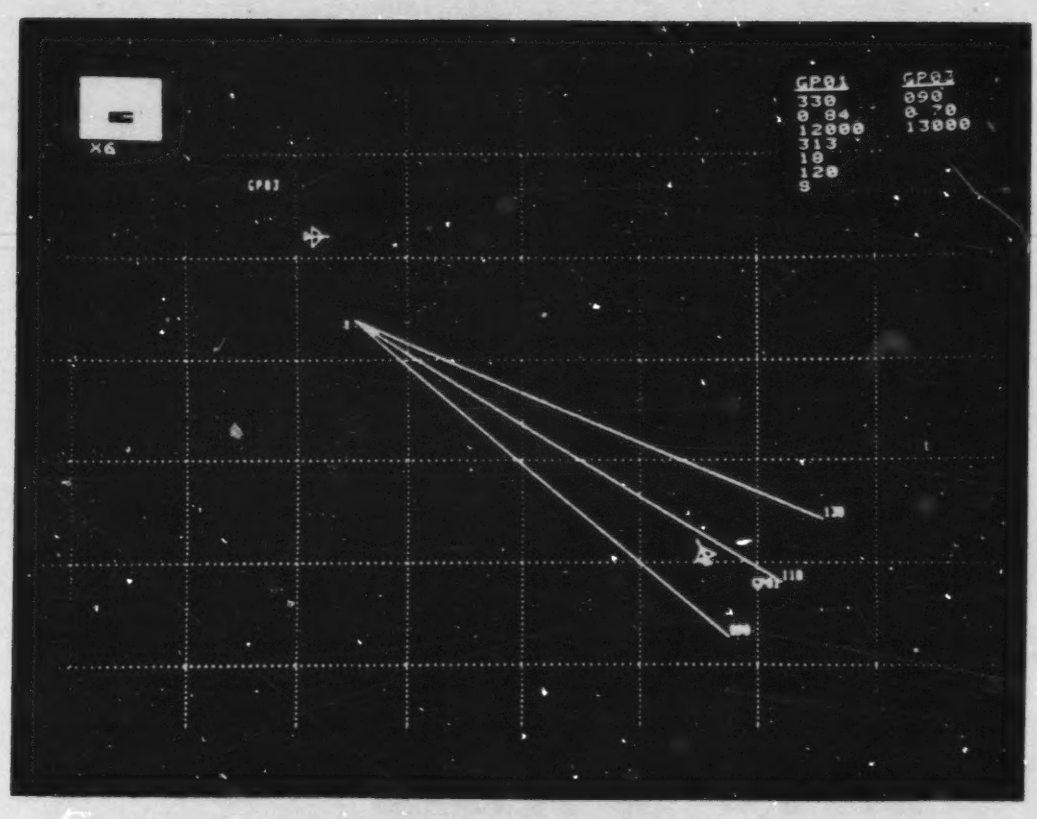

FIGURE 4. CONE-OF-ATTACK DISPLAY (STERN ATTACK).

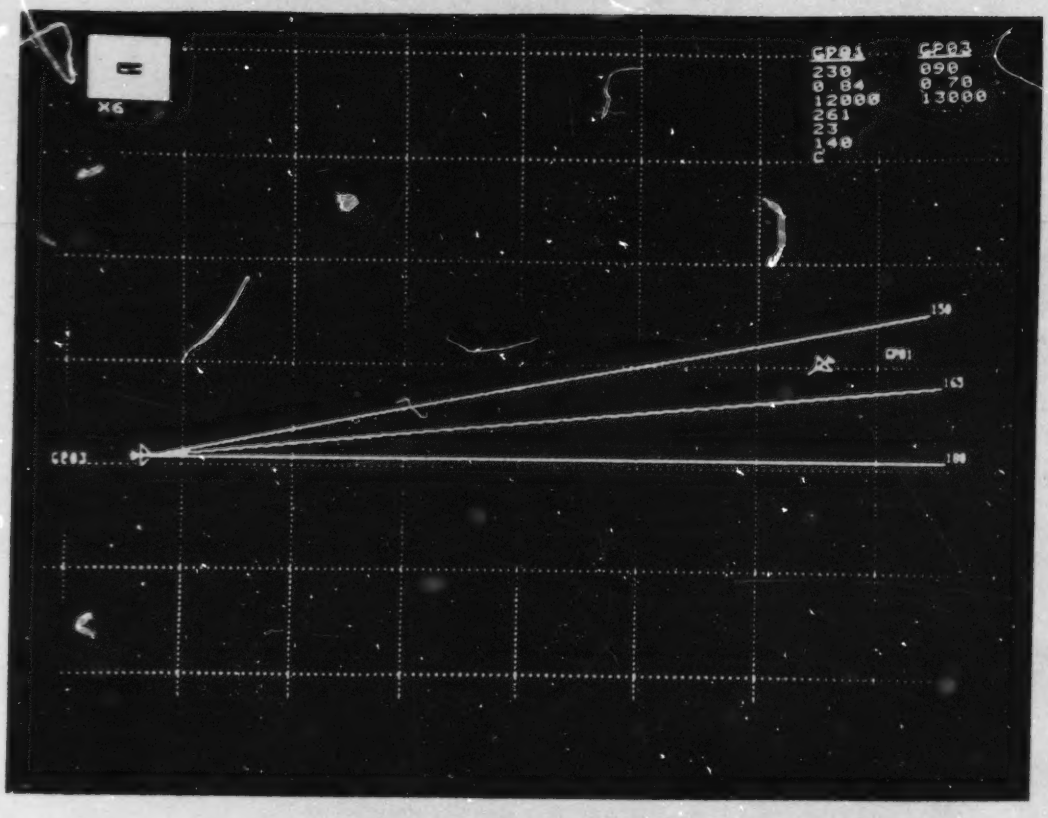

FIGURE 5. CONE-OF-ATTACK DISPLAY (CUTOFF ATTACK).

may be displayed for either the left or right side of the target, depending on which side the interceptor is approaching. The cone-of-attack display is quite useful for quickly establishing whether the interceptor is "hot" (the heading crossing angle is too great) or "cold" (the heading crossing angle is too small) on an intercept and how much correction, if any, is needed.

Intercept Vectors.

The intercept vectors display (Figure 6) is a triangle that can be shown on the display and is composed of the target heading line, the interceptor heading line, and a line representing the bearing from the interceptor to the target. Many of the conceptual issues concerning aircraft intercept geometry are based on this triangle. From a practical standpoint, this display focuses a student's attention on the expected flight paths of the interceptor and the target and on the point at which they interact, which is roughly equivalent to the intercept point. In using this display, students can quickly tell if an interceptor heading correction is needed and, if so, in which direction. Also, the graphic difference between the direction of the interceptor heading line and the bearing-to-target line demonstrates the "angle-off," which the air weapons controller verbally gives the pilot as a number, a concept which is sometimes difficult for students to understand.

Bearing Vector.

The bearing vector, as shown in Figure 7, is a simple graphics display of the bearing from an identified aircraft to the target. It is identical to the bearing vector line used as part of the intercept vectors display. The primary purpose of the bearing vector display is to focus a student's attention on the direction of this vector, since it provides a graphic portrayal of information given a pilot by the air weapons controller as a number and, again, is a concept often difficult for students to visualize and learn to use.

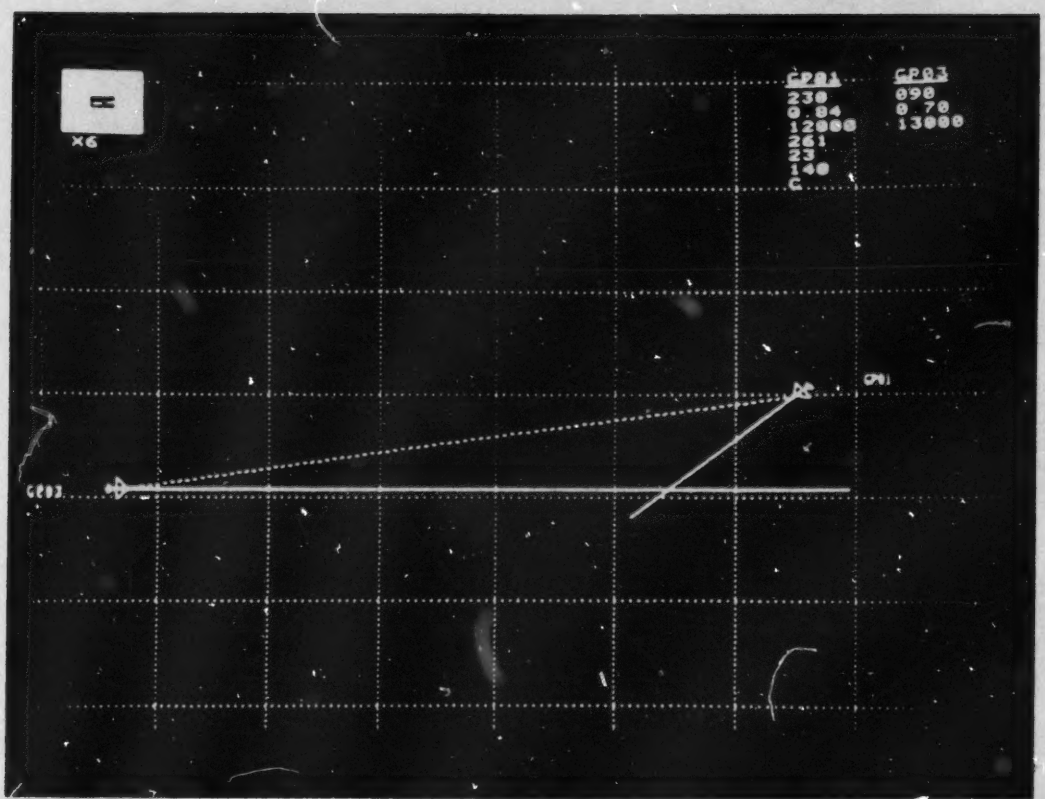

FIGURE 6. INTERCEPT VECTORS DISPLAY.

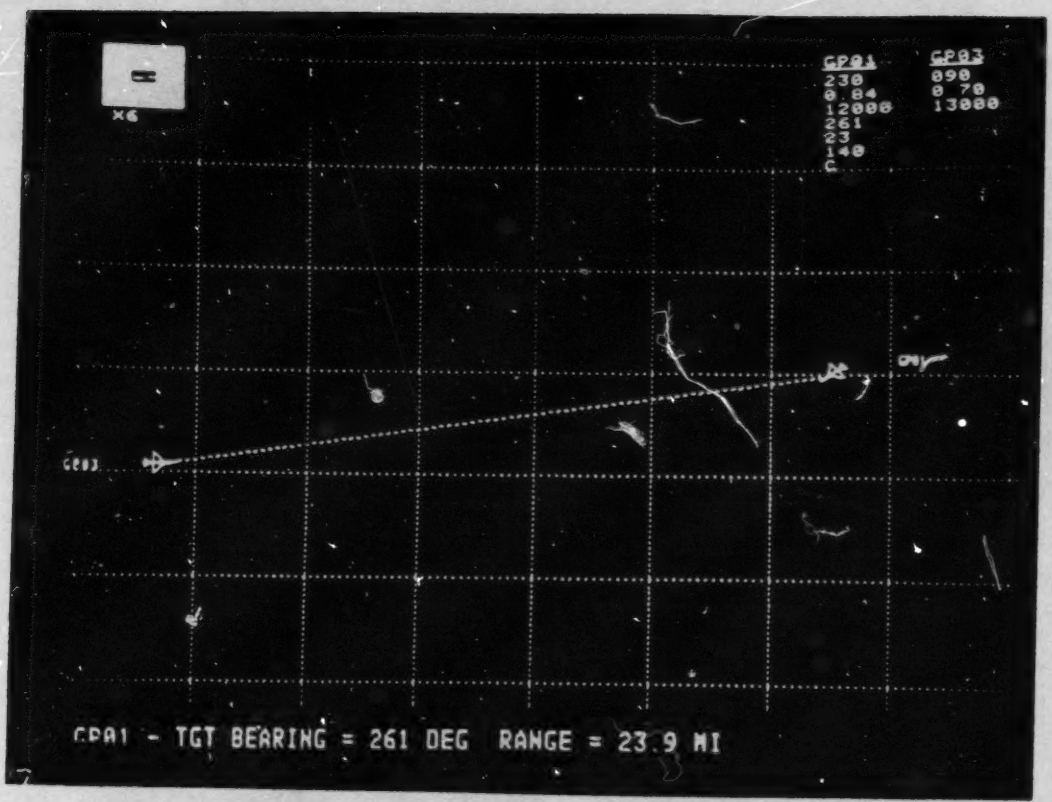

FIGURE 7. BEARING VECTOR DISPLAY.

Aircraft Flight Path Display.

One of the more interesting graphics displays is the flight path display, shown in Figure 8. This display is similar to the data trail used in SAGE- and BUIC-type automated aircraft control systems. The primary difference is that the flight path display in this experimental system is considerably longer, allowing the student to observe more of the flight path flown by the aircraft during an intercept, and thus better understand the geometry of the intercept. It is especially useful after major aircraft turns are made, because it allows the student to "look back" and see what path the aircraft have taken.

Aircraft Flight Predictor (Look-Ahead) Display.

Although both the high-resolution CRT and the TV/videotape software versions contain the preceding special graphics, the TV/videotape version has an additional graphic, the flight predictor display shown in Figure 9. With this graphic, it is possible to show the flight path of each aircraft that is predicted for approximately the next 50 frames, or approximately 30 seconds of flight. This allows a student to observe the effects of having the aircraft continue on their current headings or to see where heading changes are required in order to complete a successful intercept. This display can also be used to depict the transition point (XP), offset point (OP), turn point (TP) and intercept point (IP), although normally only the OP and TP are used.

SYSTEM USE

As described earlier, this experimental system can be used two ways: either to fly the aircraft and perform "live" intercepts using the interactive keyboard during system demonstrations, or to develop videotapes of scripted mission scenarios for later viewing in a training environment. This section will discuss briefly how the system is used

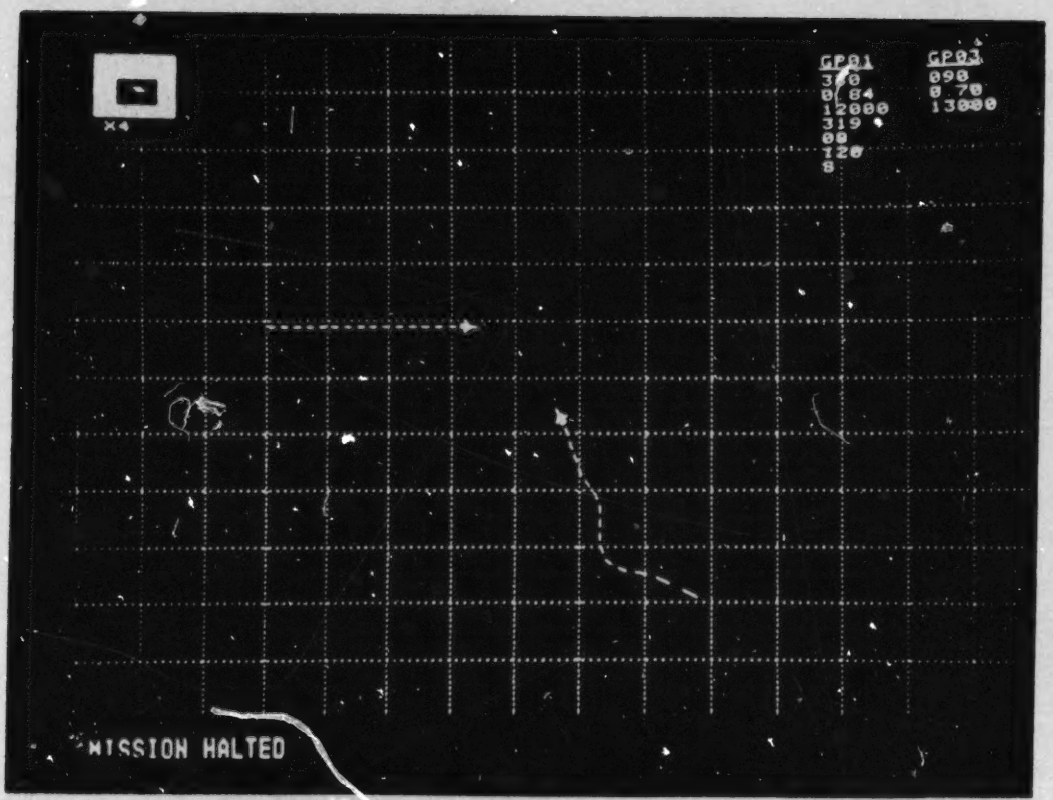

FIGURE 8. AIRCRAFT FLIGHT PATH DISPLAY.

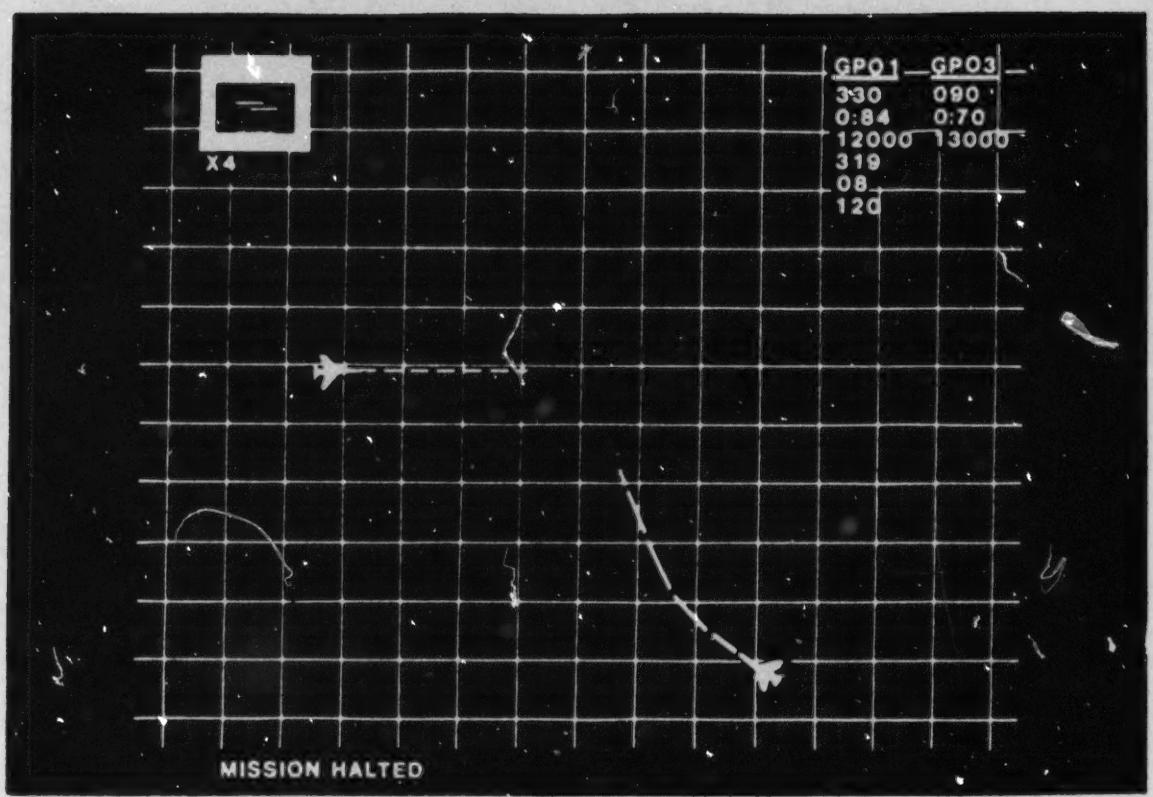

FIGURE 9. AIRCRAFT FLIGHT PREDICTOR (LOOK-AHEAD) DISPLAY.

for these two purposes, and a more in-depth discussion of system set-up and operation is included in Volume II of this technical paper.

Interactive Control.

When an operator wishes to "fly" the aircraft interactively, the proper software storage disk (high resolution CRT version) must be loaded into the disk drive, the system must be initialized, and the proper software loading instructions must be typed on the keyboard. These procedures are outlined in Volume II of this technical paper.

After these steps are accomplished, the aircraft appear in preset positions on the viewing screen and are under interactive control, starting with preset headings, speeds, and altitudes. After the number of aircraft to be displayed (either two or three) is chosen, the keyboard and viewing controls are used to manipulate the visual scene and to control the aircraft for performing intercepts. It is possible to fly either one or two interceptor aircraft against the target.

The keyboard consists of standard typewriter-style keys (letters and numbers). These are used to input most of the "verbal" commands (to the aircraft) into the computer, using language quite similar to that used with actual pilots. The operator simply types the command (e.g., GP02 LEFT 180) and then depresses the carriage return key. While the command is being typed, it is displayed on the text line at the bottom of the visual scene so that the operator can see if there are any typing errors.

Above these typewriter-style keys are two rows of user-definable function keys. Use of these keys allows software routines to be activated by pressing a single key. Most of these keys are used to display special graphics routines and to control the angle from which the visual scene is viewed (top-down, 45°-angle, and front views).

On the right side of the keyboard are the directional panning keys and the numeric pad for charging the level of zoom of the scene being displayed. These two sets of viewing controls, along with the angle-of-view function keys, are used both when controlling the aircraft interactively and when making videotapes. The function keys are further described in Volume II of this paper.

Videotape Production.

Due to the difficulty of keyboard interceptor control, it was decided that the graphics display would be presented via videotaped mission scenarios, rather than have the aircraft controlled by students interactively from the keyboard. Thus, a second version of the applications software was developed to provide this capability.

In the second software version (TV/videotape version), scripted flight plans are developed for each aircraft using software commands and are then integrated to form a mission scenario that can run automatically from beginning to end, rather than having the aircraft flown interactively from the keyboard. This allows the development of scenarios that focus on the specific intercept issues to be demonstrated. It also minimizes the aircraft control mistakes which would necessarily exist if the videotape development process simply consisted of recording a "live" mission flown using the interactive keyboard.

The actual process of developing mission scenarios is quite time-consuming but has many advantages over other approaches. The target and interceptor flight paths are sketched on paper and reviewed by training instructors to make sure that the correct intercept tactics are being displayed. Then the aircraft are flown interactively and a listing of the commands used to control the aircraft is compiled. This step is repeated until a set of software commands (i.e., a flight plan) is developed which allows the aircraft to fly the mission under software

control, rather than from the interactive keyboard. Finally, the display of the relevant special graphics relating to the intercept geometry issues is added to the software listing and any final changes that may be necessary are made to the flight plan. When this process is completed, the entire mission can be run by the typing of a single command to initiate the flight plan, except for the viewing controls as discussed previously, and the whole mission is recorded directly from the computer output onto a videotape.

The final step in developing videotapes for instructional purposes is to develop an instructor script to accompany the mission scenario and to record this script onto the voice track of the videotape. Thus far, two videotapes have been produced using this system: one to address the stern intercept tactic and one for the cutoff intercept tactic.

SECTION 3 - DISCUSSION

SUMMARY

This effort was conducted at the request of the Tactical Air Command to improve the training of Air Force air weapons controllers by development and application of advanced computer graphics training technology. More specifically, the issue of training aircraft intercept tactics and geometry, especially those relevant to three-dimensional airspace issues, were the focus of this research and development effort. In order to display these types of concepts, a simulated three-dimensional computer graphics aircraft intercept animation was developed.

This display capability was developed because issues deemed critical to the training of air weapons controllers are very difficult to address adequately with either standard two-dimensional radar displays or by classroom lectures and demonstrations. The animated display that was developed provides the capability to display and control up to three aircraft, a low fidelity visual scene, a dynamic aircraft information display, and special graphics which illustrate the critical training concepts involved in performing aircraft intercepts. This developmental system may be used to plan complete scripted mission scenarios and to videotape them for later student viewing. Two 35-minute videotapes were developed for use in the USAF Interceptor Weapons School (IWS) air weapons controller training program: one to address the issues critical for performing the stern intercept tactic and one for the cutoff intercept tactic. Preliminary feedback from IWS indicates that the students are pleased with the display and believe that it helps them in better understanding intercept tactics and geometry.

Although this effort demonstrated the feasibility of addressing issues critical to the training of air weapons controllers, there were

many technological issues that were encountered for which fully adequate solutions were not able to be found within the scope of this initial effort. The remainder of this section will discuss these issues.

TECHNICAL ISSUES

Raster Scan Technology.

Because of its superior display qualities, including the capability to display many colors, and the necessity of presenting more than just a plain, black background, it was decided to use a raster scan, instead of a vector graphics, display system; however, a major disadvantage to the raster scan technology is that it has a slower animation display rate. One option available for future systems is the use of two microprocessor central processing units (CPUs) instead of the normal single CPU; one manufacturer estimates that this will produce a refresh rate that is 10 times faster.

Simulated Three-Dimensional Cues.

Providing adequate simulated three-dimensional depth cues was a primary concern during this effort. Three options were available for displaying the aircraft: vectors (with an open body), filled (with the body of the aircraft drawn), and shaded (with light and dark shadows from a simulated external light source). Although these three options, respectively, have an increasing degree of simulated three-dimensional depth perception cues associated with them, increasing these cues caused a significantly slower refresh rate. Thus, it was necessary to use the vector approach, which has the least amount of simulated three-dimensional cues, in order to maximize the framing rate.

The only other visual simulated three-dimensional cue on the display is the representation of the airspace and the ground. Because

most of the available visual depth cues are associated with the relationship between the aircraft and the ground, the choice as to how best to display the airspace and ground was a critical one. Several different options were developed and evaluated during the project. The results of these evaluations were that the more complex displays, such as a gridded cube representing the airspace, drew the attention of the operator and interfered with observation of the aircraft. The final choice was a simple representation of the ground, which rotated to provide views of the scene from different angles. One possibility for future systems is to provide a ground representation that is similar to the one developed in this effort, but which includes low fidelity representations of terrain features, such as hills and valleys, and man-made structures, such as buildings and roads. The use of dual CPUs could make the use of this more complex ground display possible and should increase the perception of a simulated three-dimensional airspace. Other ideas, such as vertical lines from the aircraft to the ground to represent aircraft altitude, also deserve attention.

Interactive Control.

The major technical difficulty encountered during this effort was the use of a keyboard to control the movement of the aircraft interactively. The majority of the evaluations by persons from various air weapons controller training staffs indicated that using the keyboard to control the aircraft would be too difficult for many students. Because focusing attention on the visual scene and the issues being displayed was more important than actually controlling the aircraft, the work was redirected toward producing videotaped mission scenarios for students to observe. In this way, students could concentrate on observing the visual scene and the special graphics oriented toward the aircraft intercept issues without interference from the task of typing commands on the keyboard.

One possibility that should be considered for similar systems in the future is to use a voice recognition system to handle the task of

in-putting commands to the aircraft. In this manner, it would be possible to maintain an interactive system where students could practice controlling the aircraft but not be distracted from viewing the visual scene. Other training systems for students performing less complex command and control functions have successfully used voice recognition technology to allow a student to speak natural language commands directly to the computer. (e.g., Breaux, Curran, and Huff, 1978; Breaux, McCauley, and Van Hemel, 1981; Chatfield, Klein and Coons, 1981; Dixon and Martin, 1979; Hicklin, et al., 1980; Lea, 1980; McCauley, Root, and Muckler, 1982; Poock, 1980)

Type of Training.

Three primary issues are involved in the conceptual design of this type of training system. The first, and most important, deals with whether the system will be used to train air weapons controller students on concepts and tasks that are primarily procedural in nature or will be used to develop higher-level cognitive skills. Most of the applied research in this area has focused on the more procedural and visual perception aspects of the type of tasks performed by the air weapons controller. However, many higher-order information-processing and decision-making functions are being performed, such as those being investigated by Kelly, Greitzer, and Hershman (1981) and by Kelly and Greitzer (1982). These researchers examined decision-making performance in a simulated command and control operations task and found that information-processing and decision-making performance were significantly affected by task load. They developed a heuristic model including executive review, detection, and decision-making as the major information-processing components. These types of skills are not addressed in the training programs currently available to air weapons controllers. Further R&D is needed to delineate the procedural, automated aspects of this job versus the higher-level, information-processing and decision-making aspects and to decide how each of these should be addressed by future training systems for this occupation.

The second issue concerns the importance of individual versus team training. Although the job of the air weapons controller is predominantly an individual one, many team tasks are required for the effective functioning of the weapons teams in their command and control environment, such as the coordination of resource allocations. Although the system developed in this effort deals only with the individual aspects of this job, follow-on efforts should be expanded to address the information flow and communications requirements of the weapons teams.

The third issue related to the type of training to be provided concerns the role of the instructor in the training process. There are trade-offs to be made between assigning tasks to an actual instructor versus having the computer perform the training and performance assessment functions. At one end of the continuum, the computer can be used only to provide the graphics simulation, with the instructor performing all of the other tasks. This is similar to the way in which the current training equipment is used. At the other end of the continuum, the computer can perform the display, training, and performance measurement tasks through the implementation of advanced computer-managed instruction techniques. The latter alternative includes having the computer present coherent, branched lesson plans, as well as performance assessment and feedback to the student. A separate study would need to be performed to evaluate the cost effectiveness of assigning training tasks alternatively to an instructor or to the computer in such a way as to maximize the effectiveness of both.

Visual Display

Although considerable R&D work on visual perception and training device display requirements has been conducted (e.g., Biberman, 1973; Christ, 1975; Huggins and Getty, 1981; and Lenzycki and Finley, 1980), the difficulties encountered in this effort indicate that additional R&D is needed on the visual display requirements for this particular type of system, primarily because of the new technologies involved and the fact

that it is a simulated three-dimensional display. Issues which need to be addressed in further research include: type of display (single screen, split screen, or dual displays), level of visual resolution in the pixel configuration (high - 1024 X 1024, medium - 480 X 512, low - 240 X 240), color coding choices for different components of the display, level of fidelity of the aircraft and visual scene, aircraft shape and drawing style (vector outline, filled block, full shading), manner in which the airspace and ground are represented (cube, flat surface, contoured surface), and alphanumeric information display requirements.

Simulated Three-Dimensional Perspective.

One of the major issues of importance to this effort concerned how much emphasis should be placed on the simulated three-dimensional-perspective view of the airspace versus presenting the special intercept geometry graphics using the top-down, two-dimensional perspective. At the beginning of this effort, it was expected that the three-dimensional geometry of an intercept would be of prime importance. However, as the work progressed and more discussions were held with various instructors, it began to appear that, although some important benefits could be derived from observing the three-dimensional aspects of intercepts, the intercept geometry, itself, was most easily understood by viewing it from a two-dimensional perspective. The final videotapes, then, incorporate both perspectives, depending on what concept the recorded instructor voice is addressing at each point in the intercept. This area needs much more study in order to specify the need for each of these two perspectives in training systems for air weapons controllers. Virtually all of the instructors involved in this effort agreed that the simulated three-dimensional perspective was beneficial in understanding how aircraft intercepts occur, but so far, no applied research has been conducted to address the issue of which concepts need the use of this type of display and which do not.

CONCLUSIONS

This exploratory research and development effort has successfully demonstrated that a simulated three-dimensional computer graphics supplemental training system for air weapons controllers is a viable concept. The simulation display that was developed resulted in the production of two videotapes for use in the IWS training program. It is planned that these videotapes will be shown to all IWS students during their third week of training as a review of intercept tactics and procedures and will be available for individual student viewing throughout their training.

Initial use of the stern intercept videotape indicates that the students believe it to be beneficial in understanding aircraft intercept geometry, whereas some of the instructors are much less certain about its value. It was not possible within the scope of this effort to empirically evaluate the effects of student viewing of the videotapes on actual performance. Thus, no definitive conclusions can be drawn regarding the usefulness of the videotapes. Future research and development projects in this area need to include this type of evaluation.

It is believed that an interactive simulated three-dimensional display system can be developed to address training issues for air weapons controllers that other training technology cannot adequately train. However, there still remain several technological and training system design issues which need to be resolved through additional research and development. It is believed that the more recent advances in microcomputer technology make continuation of exploratory and advanced development on this type of training system worthwhile.

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